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ENGINEERING DESIGN DATA FOR ALUMINUM ALLOY 7050-T73651 PLATE

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Prepared for:

Air Force Materials Laboratory

August 1973

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13. ABSTRACT

Mechanical properties of aluminum alloy 7050-T73651 one-inch thick plate were determined and then compared to other high strength aluminum alloys. The fracture, fatigue crack growth, and stress corrosion properties and the flaw sensitivity index for the 7050-T73651 alloy were equal to or better than similar properties for other 7000 series aluminum alloys at similar strength levels. Conventional notched and smooth fatigue data indicated that the 7050-T73651 alloy had fatigue properties somewhat below those of 7049-T73, but equal to most other aluminum alloys. Environmental fatigue crack growth tests indicated that the crack growth rate was significantly accelerated by the presence of a 3.5 per cent sodium chloride solution environment. Changes in the specimen width were found to have an effect on the conditional fracture toughness values.

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ENGINEERING DESIGN DATA FOR

ALUMINUM ALLOY 7050-T73651 PLATE

R.E. JONES
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FOREWORD

This report was prepared by the University of Dayton Research Institute (UDRI), Dayton, Ohio. The work was performed under USAF Contract No. F33615-72-C-1282. The contract was initiated under Project No. 7381, "Materials Applications," Task No. 738106, "Engineering and Design Data," and administered by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. David C. Watson, AFML/MXE, Project Monitor.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

The authors would like to acknowledge that testing performed for this program was accomplished by Messrs. Woleslagle, Marton, and Opela of the UDRI and Mr. M. P. Gernstein of AFML/MXA.

The report covers work conducted from June 1972 to July 1973. The contractor's report number is UDRI-TR-72-33.

The report was submitted by the authors in August 1973.

This technical report has been reviewed and is approved.

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Materials Support Division

ABSTRACT

Mechanical properties of aluminum alloy 7050-T73651 one-inch thick plate were determined and then compared to other high strength aluminum alloys. The fracture, fatigue crack growth, and stress corrosion properties and the flaw sensitivity index for the 7050-T73651 alloy were equal to or better than similar properties for other 7000 series aluminum alloys at similar strength levels. Conventional notched and smooth fatigue data indicated that the 7050-T73651 alloy had fatigue properties somewhat below those of 7049-T73, but equal to most other aluminum alloys. Environmental fatigue crack growth tests indicated that the crack growth rate was significantly accelerated by the presence of a 3.5 per cent sodium chloride solution environment. Changes in the specimen width were found to have an effect on the conditional fracture toughness values.

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INTRODUCTION

The purpose of this project was to develop engineering design data for aluminum alloy 7050-T73651 plate and also to investigate some of the phenomena associated with fracture toughness and fatigue crack growth testing. Test material was purchased from the Aluminum Company of America (ALCOA) during the latter part of that period when it was designated as X7050-T73651. However, since that time the 7050 alloy has been accepted by the Aluminum Association and the "X" prefix or designation has been dropped. The fact that the material was purchased while the "X" designation was in effect should not influence the test results because the test material conformed to the currently accepted industry standards for the 7050 alloy. Throughout this report the material will be referred to with the 7050 designation.

The mechanical properties investigated include tensile, fracture toughness, fatigue, fatigue crack growth, and stress corrosion. Temperature effects on tensile and fracture toughness properties were determined. The effects of variations in specimen width on conditional fracture toughness values (K_Q) and the influence of frequency on fatigue crack growth testing were also investigated.

SECTION II

MATERIAL AND SPECIMENS

The test material was a one-inch-thick 7050-T73651 plate procured from the Aluminum Company of America (ALCOA) with a chemical composition of:

Chemical Composition (wt. %)
(Lot Number 106-385)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
0.05	0.07	2.4	< 0.01	2.2	< 0.04	6.1	0.023	0.082

The manufacturer heat treated the material by first solution heat treating at a temperature of 890°F. The soak time at temperature was in accordance with military standard MIL-H-6088E. A final artificial age at 250°F for 24 hours was followed by 24 hours at 325°F.

The tensile and compact tension fracture toughness specimen configurations are shown in Figures 1 and 2, respectively. The L and T designations for compact tension specimens are used to signify the roll (longitudinal) and transverse directions of the plate, respectively. All of the compact tension specimens were identified according to the ASTM "two letter code" with the first letter designating the direction normal to the crack plane and the second letter designating the direction of crack propagation. One-half-inch-thick precracked compact tension specimens were utilized for constant immersion stress corrosion tests (see Figure 2) while alternate immersion tests were performed with quarter-inch-diameter round specimens of the same configuration as the tensile specimens (see Figure 1). Laboratory and environmental fatigue crack growth testing was accomplished using three-quarter-inch-thick compact tension specimens

(see Figure 2). A size effect investigation on the conditional value of K_{IC}, K_Q, was performed using compact tension specimens with W/B (width/thickness) ratios of 2.0, 4.0 and 6.0. The size effect specimen configurations were as presented in Figure 3. The specimen configurations for smooth and notched fatigue testing are shown in Figures 4 and 5, respectively. The smooth fatigue specimens were polished longitudinally using a seiies of 180, 400 and 600 grit sandpapers.

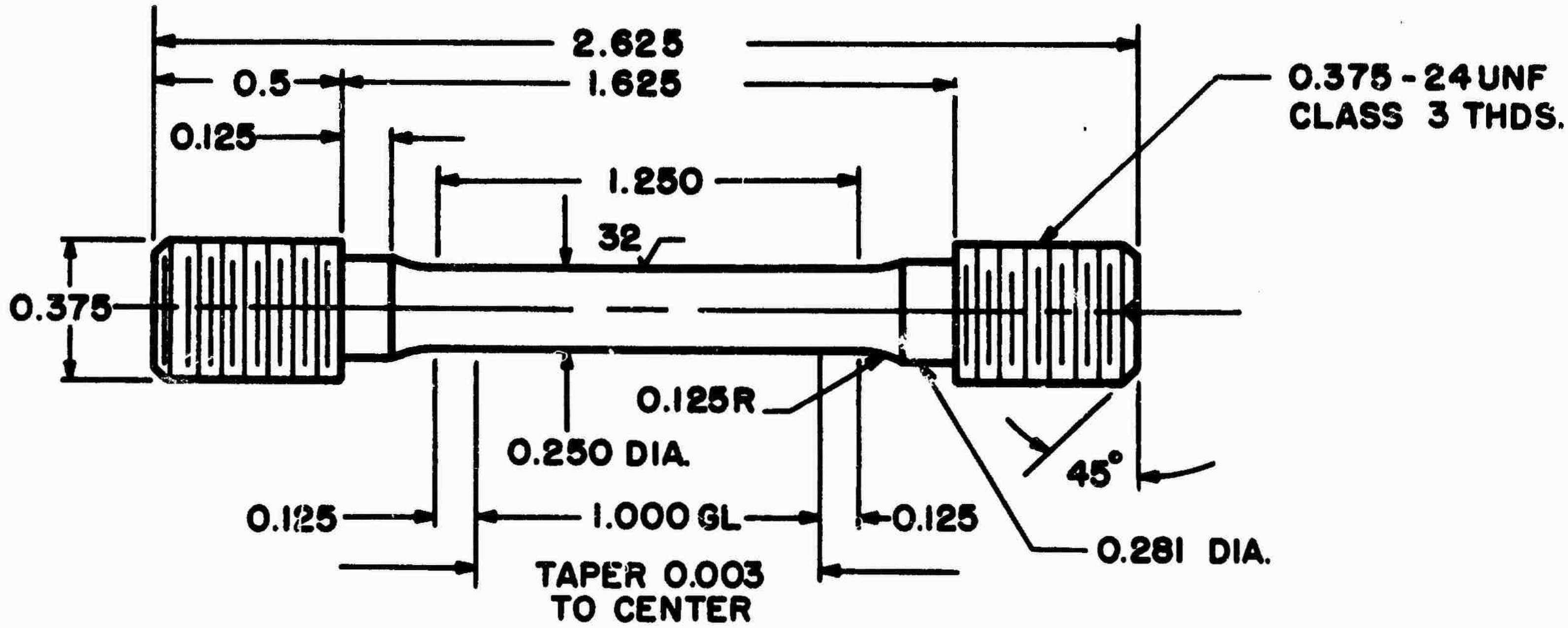
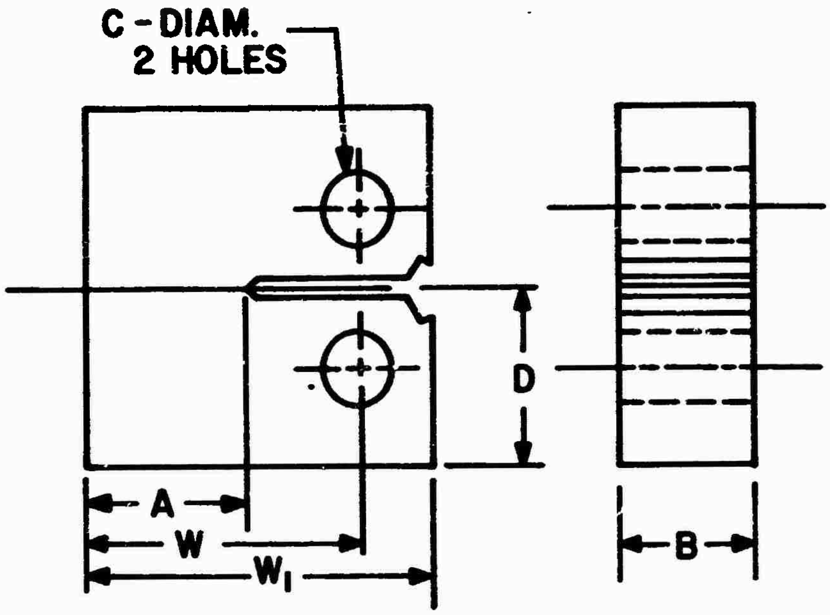


Figure 1. Tensile and Alternate Immersion Stress Corrosion Specimen Configuration



DIMENSIONS

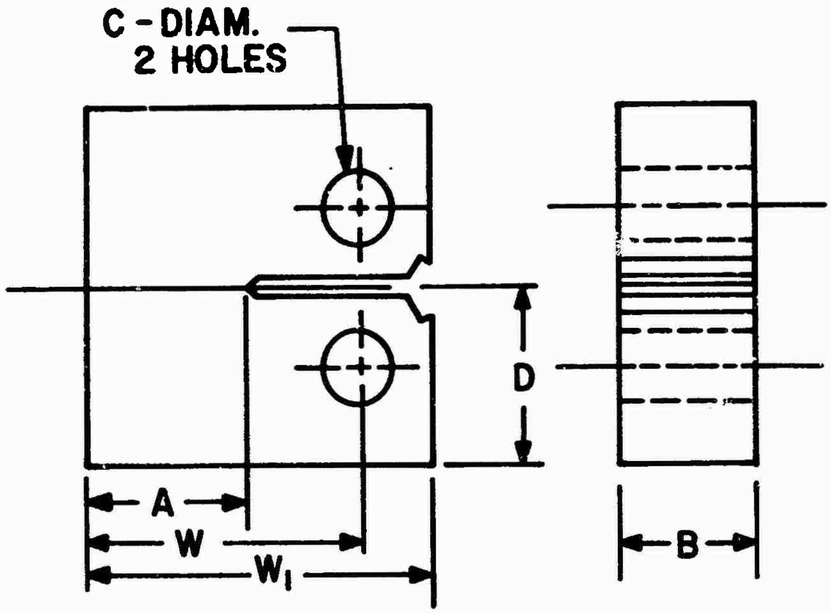
SPECIMEN THICKNESS (INCHES)	A	B	W	W_1	D	C
(a) 1	1.100	1.000	2.000	2.500	1.200	0.500
(b) 3/4	0.835	0.750	1.500	1.875	0.900	0.375
(c) 1/2	0.550	0.500	1.000	1.250	0.600	0.250

Figure 2. Compact Tension Specimen Configuration

(a) Fracture Toughness

(b) Crack Growth

(c) Precracked Stress Corrosion



All specimens have plan dimension that are proportional to the ASTM recommendations.

DIMENSIONS

SPECIMEN THICKNESS (INCHES)	W/B	A	W_1	D	C
1.000	2	1.100	2.500	1.200	0.500
1.000	4	2.150	5.000	2.400	0.630
1.000	6	3.200	7.500	3.600	1.510

Figure 3. Size Effect Compact Tension Specimen Configuration

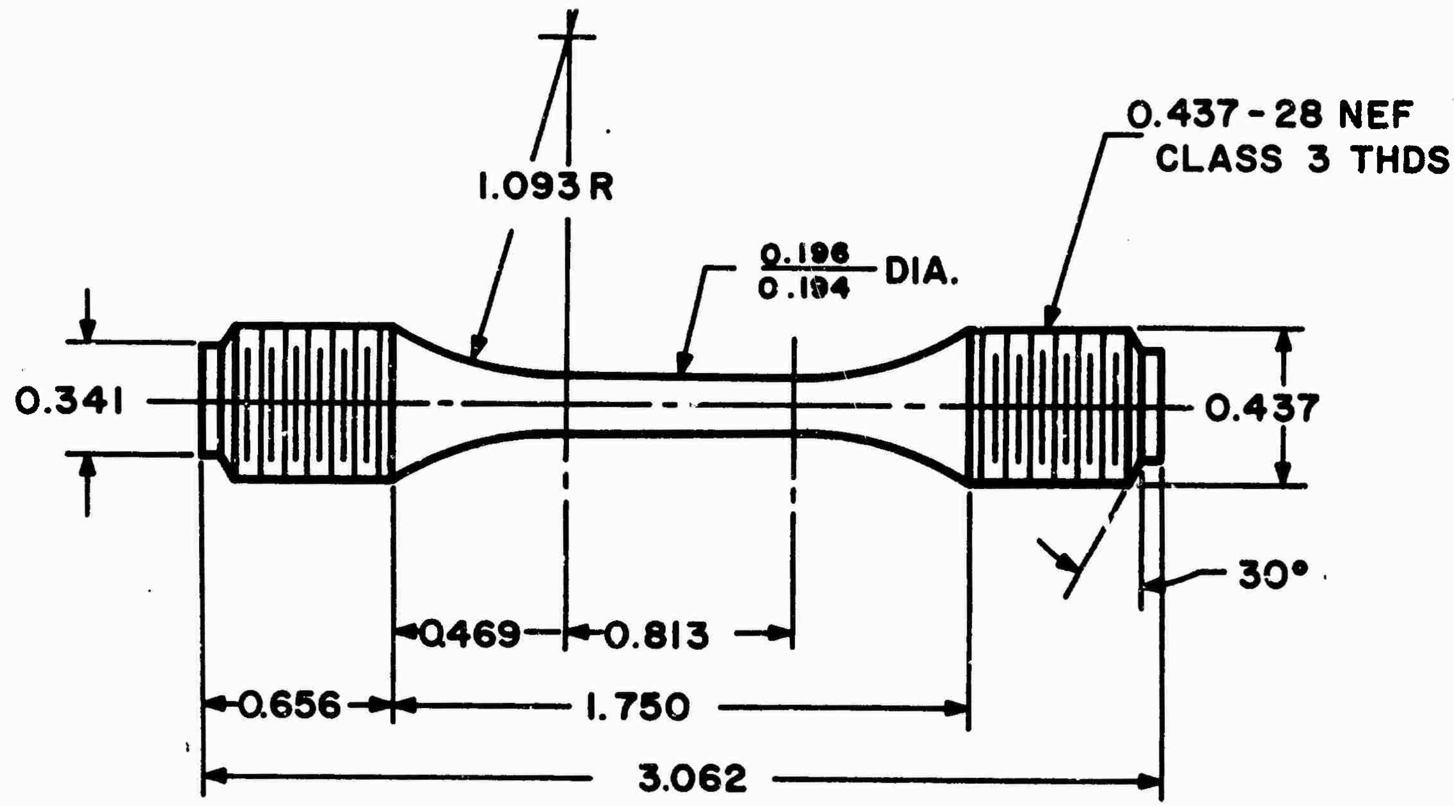


Figure 4. Smooth Fatigue Specimen Configuration

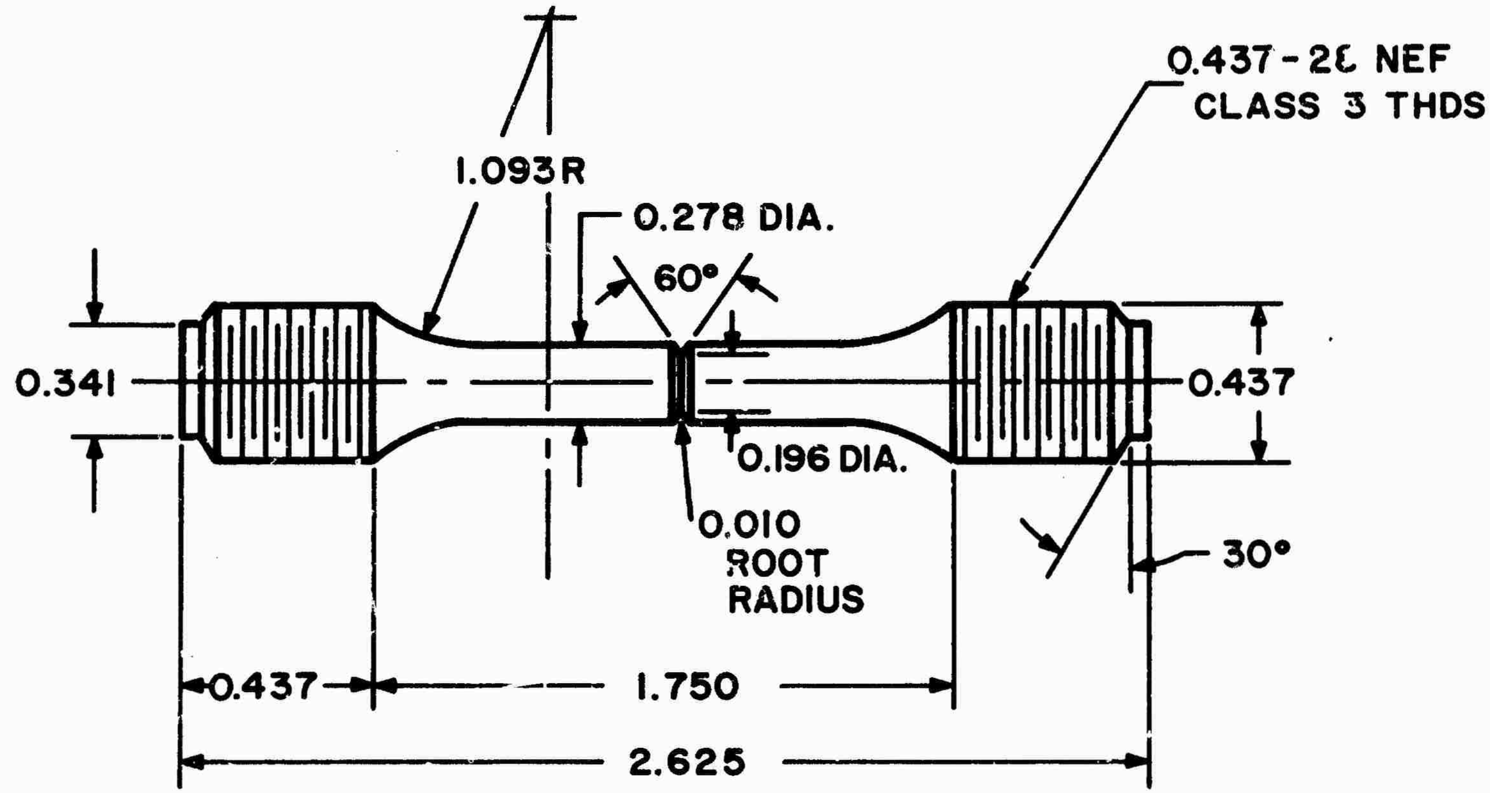


Figure 5. Notched Fatigue Specimen Configuration

SECTION III

PROCEDURES

Tensile and fracture toughness tests were performed in a Wiedemann tensile testing machine. The cryogenic and elevated temperature tests were performed in a Conrad-Missimer test chamber. This apparatus employs resistive heating elements and liquid nitrogen for heating and cooling, respectively. Precracking of all compact tension specimens was accomplished at loads less than one-third of the expected K_{IC} value with an "R ratio" (minimum fatigue load/maximum fatigue load) of 0.1 in a laboratory environment using an Amsler Vibrophore resonant fatigue machine.

Precracked compact tension stress corrosion specimens were constantly immersed in a 3.5 per cent sodium chloride solution. The round alternate immersion stress corrosion specimens were repeatedly immersed for ten minutes in a 3.5 per cent sodium chloride solution and then exposed to laboratory air for fifty minutes. Both types of stress corrosion tests were conducted in Satec creep testing machines. The precracked stress corrosion specimens were loaded at K_{Ii} (initial opening mode stress intensity) = 15, 20, 30, and 33 KSI$\sqrt{\text{IN}}$ and the round alternate immersion specimens were loaded at 60, 70, 80, and 90 per cent of the yield stress. The stress corrosion tests were terminated after 1000 hours of test if no failure occurred.

Constant amplitude crack growth tests were performed in a closed loop MTS hydraulic fatigue machine. The ambient fatigue crack growth tests were conducted in a laboratory air environment (20-40 per cent relative humidity) with an "R ratio" of 0.1 and frequencies of 25 cps and 5 cps. The corrosion fatigue crack growth testing was performed at two frequencies (5 cps and 25 cps) in a 3.5 per cent sodium chloride solution with an "R ratio" of 0.1. Crack length measurements were made on the

the specimen surface using a 30X Gaertner traveling microscope. Some of the fatigue crack growth data was analyzed by fitting an eight degree polynomial to the crack length versus cycles data and taking the derivative of this curve at selected points to obtain crack growth rates. The above operation was accomplished by programming a CDC 6600 computer (1). All of the environmental fatigue crack growth data was manually reduced.

Smooth and notched axial fatigue testing was accomplished in a laboratory air environment with a 2-ton Schenck fatigue machine at an "R ratio" of 0.1 and a loading frequency of 2000 cpm.

SECTION IV

RESULTS AND DISCUSSION

The tensile properties of 7050-T73651 plate at -65°F, 0°F, room temperature, 250°F, and 350°F are presented in TABLE 1. The room temperature ultimate and yield strengths are substantially higher than those of some other 7000 series aluminum alloys in a T7 condition such as 7075-T7351 (1 - 3/8-inch-thick plate) (2) and 7475-T761 (0.090-inch-thick sheet) (3). This is shown in TABLE II. At -65°F an increase of 8 per cent in yield strength over the room temperature value was observed while a decrease in yield strength of 22 per cent was observed at 350°F. Corresponding changes in the ultimate strength and ductility (elongation and reduction in area) were also observed.

The fracture toughness properties of 7050-T73651 plate are presented in TABLE III. For both the longitudinal (LT) and transverse (TL) directions of the plate, the standard ASTM specimen yielded valid K_{IC} values according to the present ASTM criteria. Based on these data this alloy would be classed as a high strength-high toughness material. The influence of temperature on the average toughness and the average yield strength in the longitudinal and transverse directions is shown in Figure 6. While yield strength between the longitudinal and transverse directions varied less than 3 per cent throughout the temperature range, the longitudinal and transverse fracture toughness between these two directions varied from 14 to 19 per cent throughout the temperature range. Overall, the toughness values were higher than those of 7075-T651 plate (K_{IC} = 30.0 KSI$\sqrt{\text{IN}}$ at σ_{ys} = 70.2 KSI in the longitudinal direction at room temperature). (4)

The flaw sensitivity index, FSI = $\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$, is a measure of the

relative flaw size that will cause catastrophic failure of a structure. For 7075-T651 plate, 7049-T73 bar (K_{IC} = 33.2 KSI$\sqrt{IN}$ at σ_{ys} = 73.4 KSI in the longitudinal direction at room temperature) (5), and 7050-T73651 plate these indexes are 0.183 inches, 0.205 and 0.273 inches, respectively. Therefore, the critical crack size of 7050-T73651 is larger than that of 7075-T651 or 7049-T73 at equivalent strength levels. The reference to the 7075-T651 and 7049-T73 alloys fracture characteristics was made to allow the comparison of aluminum alloys with similar strength levels.

Recent investigations by members of ASTM Committee E-24 show geometric effects on K_{IC} values for high toughness-high strength materials. Present ASTM criteria for a valid fracture toughness test include:

$$a \geq 2.5 \left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 \quad \text{(Crack Length)}$$

$$B \geq 2.5 \left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 \quad \text{(Thickness)}$$

$$W \geq 5.0 \left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 \quad \text{(Width)}$$

It was previously believed that if these criteria were followed, a consistent repetitive K_{IC} value would be obtained. Data obtained from the size effect specimens is presented in TABLE IV. The effects of specimen width (W) variation are shown in Figure 7. All of the data presented in Figure 7 is valid according to the criteria that a, $B \geq 2.5 \left(\frac{K_Q}{\sigma_{ys}}\right)^2$ and $W \geq 5.0\left(\frac{K_Q}{\sigma_{ys}}\right)^2$. The K_Q values are increasing with increasing W beyond the $W = 5.0\left(\frac{K_Q}{\sigma_{ys}}\right)^2$ curve. This is the same type of behavior reported by other investigators. However, it should also be noted that the ASTM criterion $P_{max}/P_Q < 1.10$

is violated by the non-standard size (W/B > 2) compact tension specimens (see TABLE IV). Figure 8 displays representative fracture faces for the three sizes of specimens. There appears to be a tendency for the size of the shear lips to increase with increasing specimen width (W).

The fatigue data for 7050-T73651 plate and 7049-T73 (5) bar extrusion aluminum alloys is presented in Figure 9. It is evident from Figure 9 that both the smooth and notched fatigue properties of 7050-T73651 are not as good as those of 7049-T73. It is important to understand that 7049-T73 is one of the better aluminum alloys with respect to fatigue. The comparison between these alloys was made because of similar strength levels and heat treatments.

The stress corrosion properties of the 7050-T73651 plate in the longitudinal direction were excellent. Because of a thickness limitation it was not possible to remove specimens from the short transverse direction. However, for the direction tested, no failures were obtained in either the alternate immersion tests or the precracked constant immersion tests. After completion of the 1000-hour test period, the precracked compact tension specimens were broken apart and the precrack surfaces were examined. It was noted that the precrack surfaces exhibited pitting and that there had been some corrosion crack growth for the specimens loaded at 30 and 33 KSI $\sqrt{\text{IN}}$.

The constant amplitude laboratory air and environmental fatigue crack growth properties of 7050-T73651 plate are presented in Figure 10 and Figure 11, respectively. When comparing the cracking rates of 7075-T6 sheet (6) and X7475-T61 Alclad sheet (7) with the laboratory air rates of the 7050-T73651 plate, it is observed that the cracking rates are slightly slower in the 7050-T73651 plate than the 7075-T6 sheet and almost coincident with X7475-T61 sheet below da/dn = 1.0×10^{-5} inches/cycle. The referenced fatigue crack growth data was chosen because the 7075-T6 and X7475-T61 alloys had strength levels comparable to those of 7050-T73651.

From Figure 11 it is evident that the fatigue crack growth rate is accelerated by a corrosive environment such as a 3.5 per cent sodium chloride solution. There is also a marked effect of frequency on the environmental fatigue process with the slower frequency yielding the faster growth rate. This increase in growth rate is expected due to the increased exposure time per cycle of the corrosive environment to the open crack tip. It is important to note that the change in frequency had little or no effect on the baseline (lab air) crack growth rates.

TABLE I

TENSILE DATA FOR 7050-T73651 ALUMINUM ALLOY PLATE
(1 in. thick)

Temp. (^{o}F)	Direction		Ultimate Strength (KSI)	Yield Strength (KSI)	Elongation in 1 inch G.L. (%)	Reduction of Area (%)
-65	Longitudinal		86.8	76.7	7.3	33
			87.0	74.4	12.0	32
			86.7	76.0	9.0	30
		Avg.	86.8	75.7	9.4	32
0	Longitudinal		84.1	74.1	11.0	33
			84.9	72.4	9.0	28
			83.7	73.6	12.0	34
		Avg.	84.2	73.4	10.7	32
	Transverse		82.7	72.8	6.4	15
			83.0	72.9	9.3	24
			81.7	72.6	7.0	15
			82.5	72.4	7.1	20
		Avg.	82.5	72.7	7.5	19
R.T.	Longitudinal		79.9	69.8	10.0	36
			81.0	70.1	11.0	39
		Avg.	80.5	70.0	10.5	38
	Transverse		77.7	73.6	11.0	31
			79.5	74.5	9.6	29
			78.7	68.4	12.8	33
		Avg.	78.6	72.2	11.1	31
250	Longitudinal		66.4	64.6	15.0	50
			66.4	63.7	17.0	51
			66.4	64.8	13.0	49
			66.4	64.4	15.0	50
	Transverse		63.2	62.6	13.0	37
			62.8	62.5	17.0	40
			64.1	62.4	14.0	49
		Avg.	63.4	62.5	14.7	42
350	Longitudinal		54.7	54.5	19.0	62
			54.9	54.9	17.0	62
		Avg.	54.8	54.7	18.0	62
	Transverse		56.9	55.4	15.0	46
			55.5	54.5	15.0	55
		Avg.	56.2	54.9	15.0	51

TABLE II

ROOM TEMPERATURE TENSILE PROPERTIES OF THREE HIGH STRENGTH AND HIGH TOUGHNESS ALUMINUM ALLOYS

Alloy	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Elongation in 1 in. G. L. (%)
7050-T73651 (1 in. plate)	longitudinal	80.5	70.0	10.5
	transverse	78.6	72.2	11.1
7075-T7351 (2) (1- 3/8 in. plate)	longitudinal	72.4	61.2	12.0
	transverse	70.4	60.0	11.0
7475-T761 (3) (0.090 in. sheet)	longitudinal	70.2	62.0	13.3
	transverse	70.8	61.4	13.3

TABLE III

FRACTURE TOUGHNESS PROPERTIES OF 7050-T73651 PLATE
(1 inch thick)

Direction	Temperature (^{o}F)		K_{IC} (KSI IN)
Longitudinal (LT)	-65		35.2
			34.9
		Avg.	35.0
	0		38.0
			36.4
		Avg.	37.2
	RT		36.8
			35.7
			37.4
		Avg.	36.6
	250		37.5
			37.1
		Avg.	37.3
Transverse (TL)	-65		30.4
			30.0
		Avg.	30.2
	0		31.3
			31.2
			31.6
			31.2
		Avg.	31.3
	RT		32.3
			32.1
			32.1
		Avg.	32.2

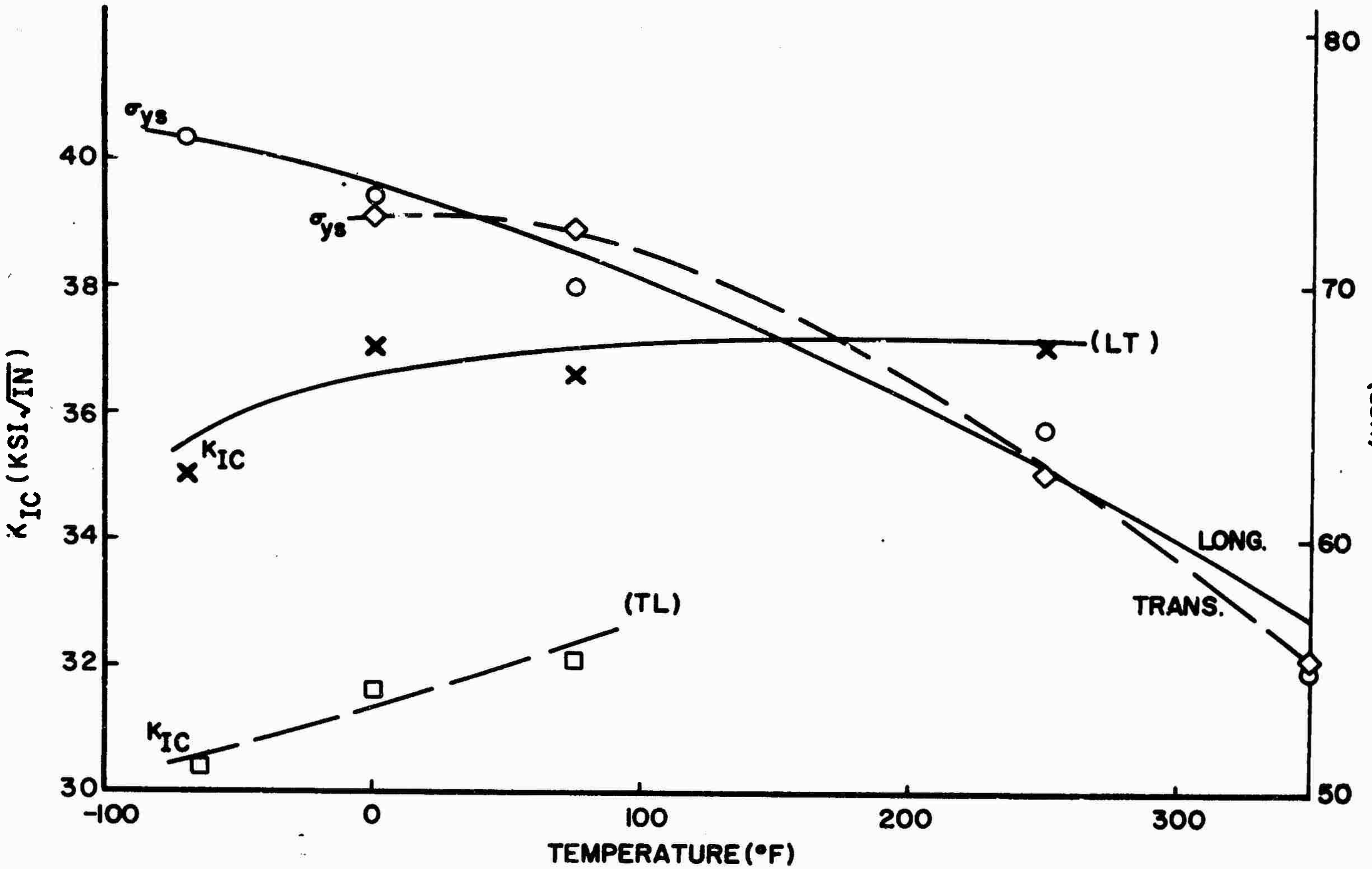


Figure 6.. Dependence of Yield Strength and Fracture Toughness on Temperature for 7050-T73651 Plate in Longitudinal (LT) and Transverse (TL) Directions

TABLE IV

ROOM TEMPERATURE K_Q VALUES FOR 7050-T73651

ALUMINUM PLATE (B = 1 Inch For All Specimens)

Direction	W/B	P_{max}/P_Q	K_C (KSI$\sqrt{IN}$)	
Longitudinal (LT)	2*	1.08	36.8	
	2*	1.06	35.7	
	2*	1.00	37.4	
			36.6	Avg.
Longitudinal (LT)	4	1.12	39.7	
	4	1.25	40.2	
	4	1.13	41.6	
			40.5	Avg.
Longitudinal (LT)	6	1.57	42.4	
	6	1.20	42.6	
	6	1.24	42.9	
			43.0	Avg.

*Standard proportioned ASTM Specimen.

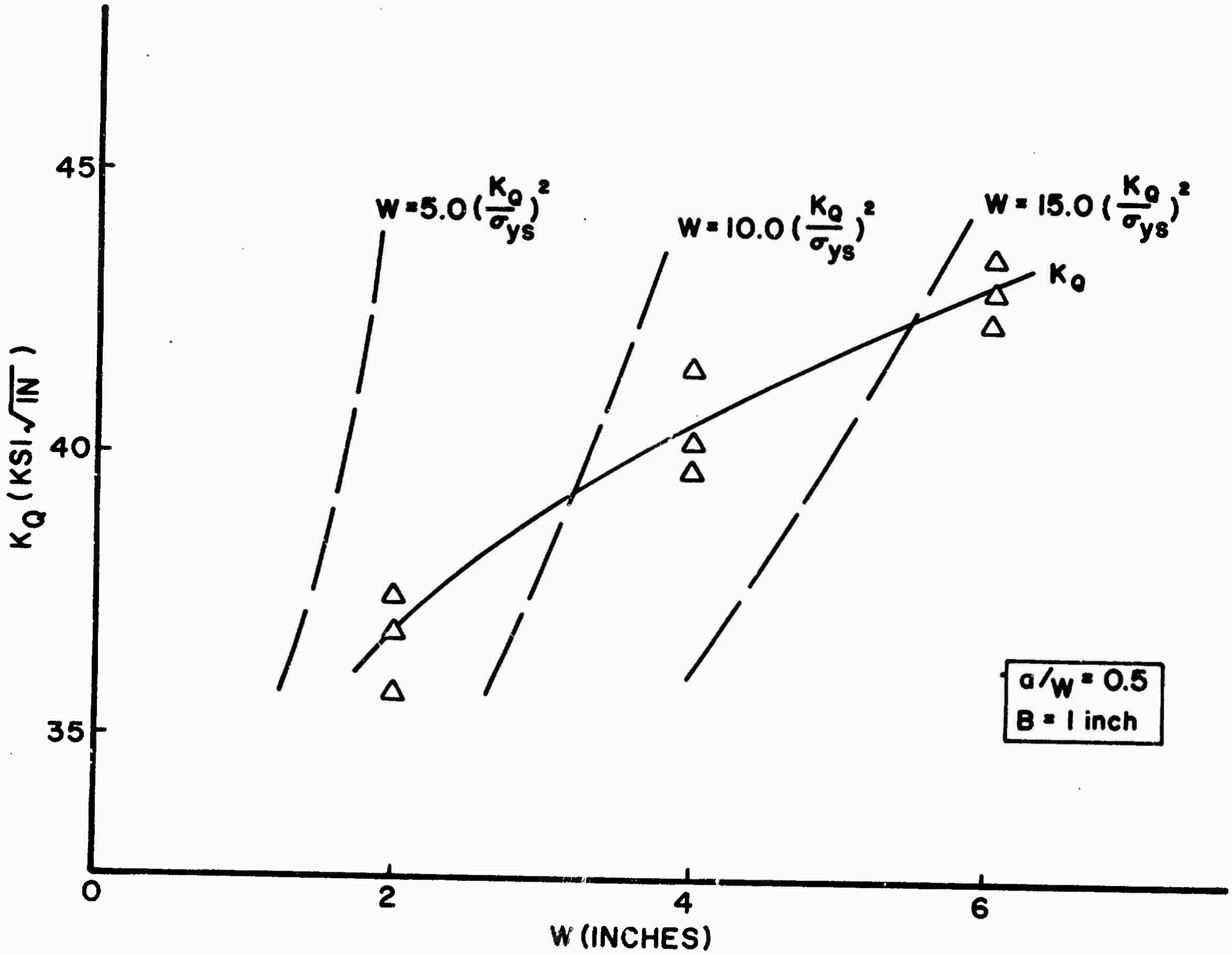


Figure 7. Effect of Compact Tension Specimen Width (W) on K_Q Values for 7050-T73651 Plate

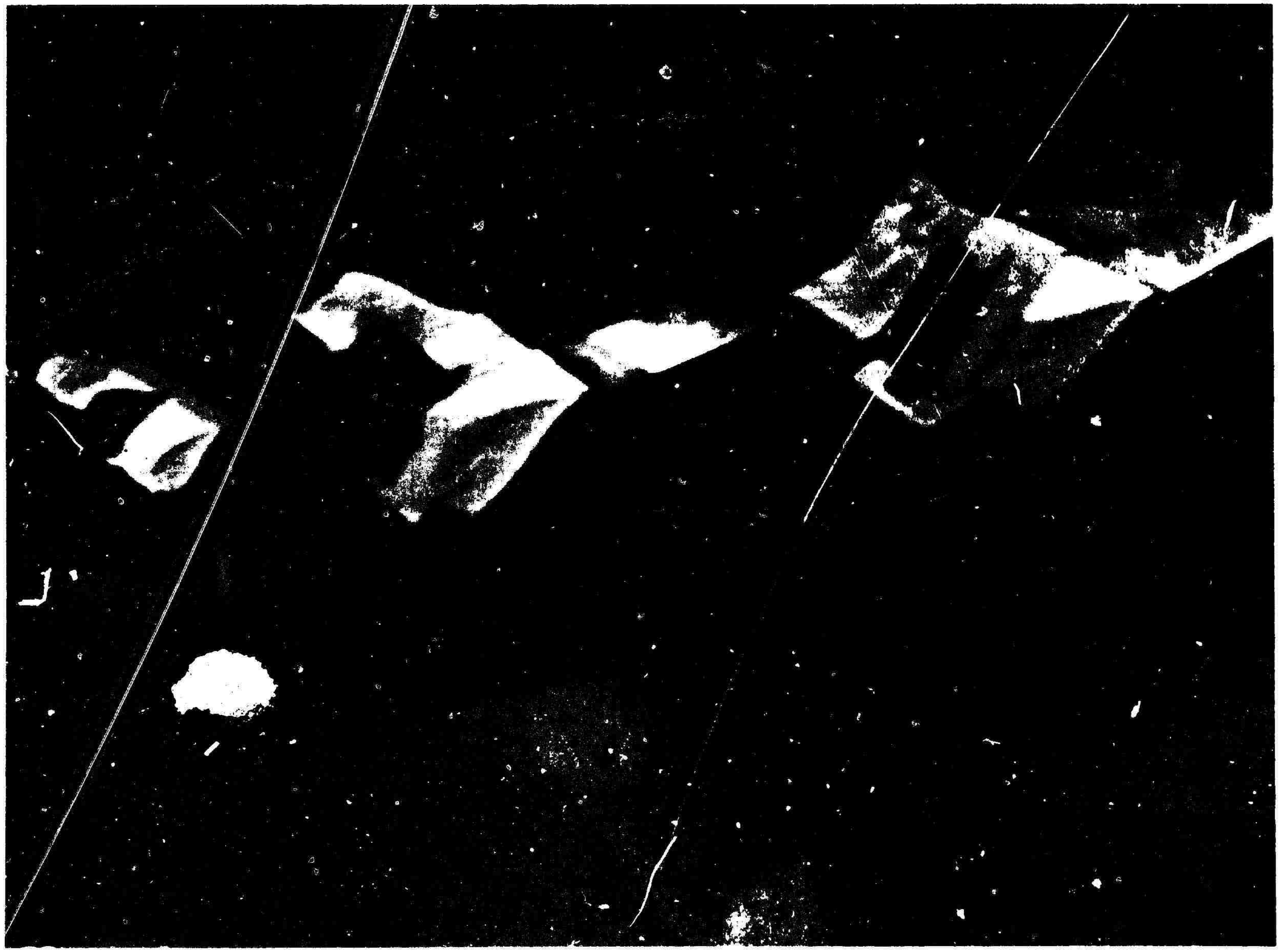


Figure 8. Fracture Faces of Size Effect Specimens

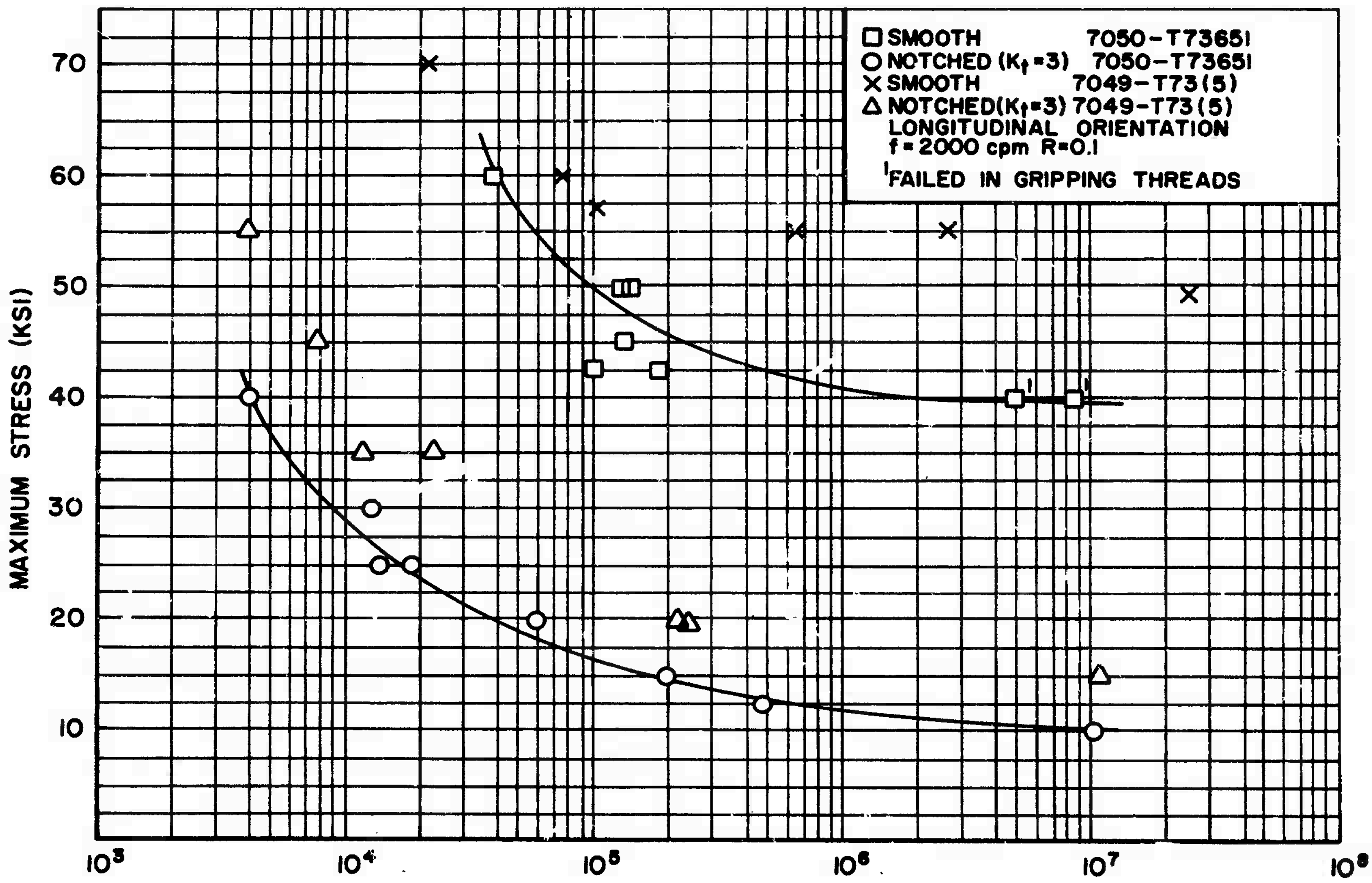


Figure 9. Fatigue Curve for 7050-T73651 Aluminum Alloy

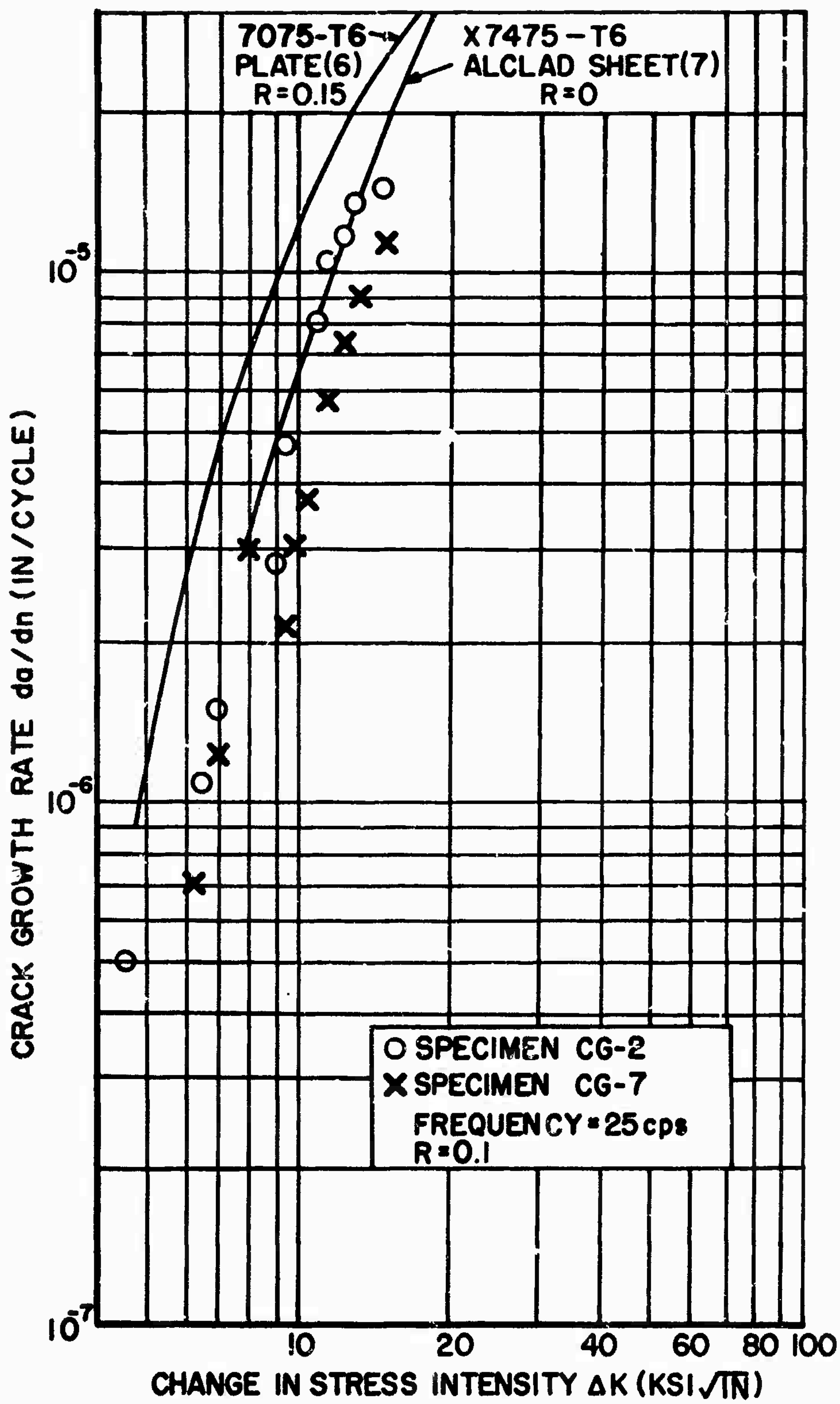


Figure 10. 7050-T73651 Crack Growth Curves for a Laboratory Environment.

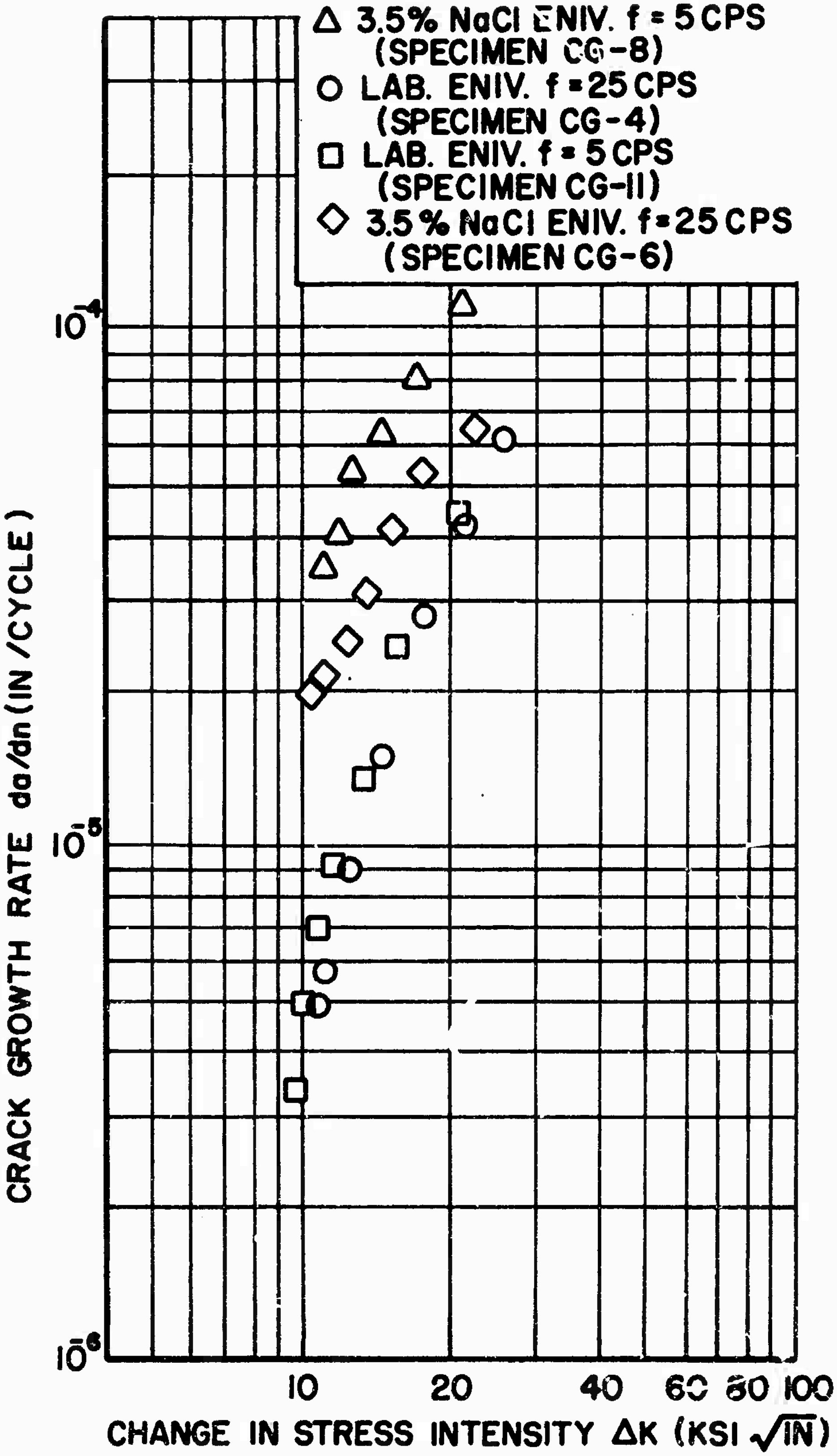


Figure 11. Graph of Crack Growth Rate Versus Change in Stress Intensity For Aluminum Alloy 7050-T73651 (R=0.1, B=0.750 Inch, and W=1.500 Inch)

SECTION V

SUMMARY AND RECOMMENDATIONS

The 7050-T73651 one-inch-thick plate has an excellent strength-toughness combination and flaw sensitivity index compared to other presently used high strength aluminum alloys. Thicker sections should be evaluated to determine if these properties are degraded in sections over 1 inch.

Stress corrosion does not appear to be a problem for the alloy in the longitudinal direction. The longitudinal direction was the only orientation checked for stress corrosion sensitivity due to a material thickness limitation. It should be noted that the short transverse direction is the orientation most susceptible to stress corrosion for the aluminum alloys. The high copper content in the 7050-alloy suggests a quench sensitivity and thus a possible stress corrosion problem in thick sections (8). Stress corrosion tests should be performed for the short transverse orientation.

The longitudinal fatigue properties for 7050-T73651 plate, while good, are lower than those for 7049-T73 bar extrusion. Additional fatigue tests should be performed to define the properties for the transverse and short transverse orientations.

Fatigue crack growth rates for 7050-T73651 appear to be comparable or slower than the rates of most other high strength aluminum alloys, but there is a significant effect of environment on the fatigue crack growth rates indicating that the 7050 alloy should be tested in the anticipated environment under the actual load levels and frequencies.

The conditional fracture toughness values $\left(K_Q\right)$ were influenced by changes in the specimen width. As the specimen was increased beyond the present ASTM width criteria, the K_Q values also increased. However, for all the K_Q values which exceeded the ASTM standard width to thickness criterion, the ASTM load criterion was also violated.

SECTION V

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